Advances in surgical care: Management of severe burn injury

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Background: **Management of combat casualties with severe burns and associated traumatic injuries requires a coordinated interaction of surgical, critical care, and evacuation assets. These patients present enormous challenges to the entire medical system as a result of the severity of injury combined with the great distance required for transport to definitive care.**

Objective: **The objective of this study was to review and highlight some of the advances in burn critical care experienced during recent combat operations. This review focuses on initial resuscitation, respiratory support, care of the burn wound, and long range evacuation.**

Data Source: **The authors conducted a search of the MEDLINE database and manual review of published articles and abstracts from national and international meetings in addition to Institute of Surgical Research Burn Center registry.**

Conclusions: **Fluid resuscitation during the first 24 to 48 hrs after injury remains a significant challenge for all who manage burn casualties. Guidelines have been developed in an effort to standardize fluid resuscitation during this time. These guidelines along with the standardization of burn wound care and continued provider education have resulted in decreased morbidity and mortality in severely burned patients returning from war zones. This system of care for severely burned patients facilitates the transfer of the burn casualty between healthcare providers and facilities and is now being integrated into the catchment area for the Institute of Surgical Research Burn Center. (Crit Care Med 2008; 36[Suppl.]:S318–S324)**

Key Words: burns; burn wounds; burn units; trauma; fluid therapy; resuscitation; humans; life support care; respiratory support; evacuation; military medicine; military personnel; Iraq; Afghanistan; United States; war

In the United States, 500,000 people seek treatment for burn injuries each year. Of those injured, 40,000 required hospitalization and more than half were admitted to specialized burn centers. Burn injuries are commonly associated with dwelling fires, motor vehicle crashes, and work-related accidents and account for 4,000 deaths annually (1). In combat, burn injury accounts for 5% to 10% of combat casualties (2). Warriors may sustain thermal injuries from a variety of mechanisms, including explosions related to incendiary devices and the surrounding flame as well as fire, which occurs secondary to the primary explosion as nearby combustible materials ignite. However, in the austere environment of the overseas military post, the hazards associated with everyday life such as burning refuse or refueling operations also contribute to injuries.

Whether the thermal injury occurs in a military or civilian environment, the severity of burn is generally determined by the intensity of the thermal energy to which the patient is exposed, the duration of exposure, and the body areas affected. The pattern of injury for military casualties is also often related to the protective equipment worn at the time of exposure to the thermal energy. Unless specifically working in an environment known for higher risk of thermal or chemical exposure such as firefighters, most civilians are wearing their normal clothing at the time they are burned. Military personnel routinely wear durable uniforms, adding additional protection based on anticipated threats. Despite active efforts to ensure optimal protection against flame for the combatant, the face and hands continue to be those areas least protected resulting in significant burns to these areas (3).

The civilian burn patient in the United States is assessed and treated at the place of injury by emergency medical services personnel and rapidly transferred by ground or air ambulance to the closest available medical facility, which may then transfer the patient to a regional burn center. The civilian patient is generally admitted to no more than two medical facilities during his or her hospital course. Although transport distances may be considerable for persons living in remote regions of the United States, most civilian burn patients can be transported from the site of injury to a definitive care facility within a few hours (4). In contrast to most civilians, however, the military burn patient is often transported to one or more intermediary facilities before final evacuation by air thousands of miles back to the United States for definitive care; nearly all military burn casualties are transferred to the U.S. Army Institute of Surgical Research (USAISR) burn center in San Antonio, TX, within 96 hrs of injury.

The process of caring for patients sustaining burns in a combat zone can also be complicated by the presence of multiple open wounds sustained in a dirty environment combined with hemorrhage related to the traumatic insult (5, 6). Operative intervention for lifesaving treatment or stabilization is not uncommon before the patient being evacuated out of the theater of operations resulting from the presence of multiple other injuries (7).

Initial Assessment and Management

Successful treatment of all burn casualties starts with a thorough assessment

From the U.S. Army Institute of Surgical Research, Fort Sam Houston, TX.

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of the patient soon after the time of injury. In a combat zone, this requires a combined strategy of airway assessment and protection, identification of hemorrhage and simultaneous control of bleeding, and initiation of resuscitation. It is easy for the initial provider to become focused on burns wounds that involve a large portion of the patient's total body surface area (TBSA). However, the graphic nature of burn wounds must be momentarily ignored to search for what may be less obvious but much more life-threatening injuries.

The initial management of the multitrauma patient proceeds in a stepwise process as outlined by the Advanced Trauma Life Support guidelines of the American College of Surgeons Committee on Trauma (8). The principles described in the Advanced Burn Life Support course sponsored by the American Burn Association (ABA) mirror those of Advanced Trauma Life Support (9). Casualties with severe burns involving the face and those with clinical evidence of inhalation injury such as stridor or production of carbonaceous sputum require early airway protection by intubation and subsequent support with mechanical ventilation. Smoke inhalation injury, seen in approximately 10% of burn injuries from both military and civilian series, increases fluid requirements during resuscitation (6). These patients should be intubated with the largest caliber tube possible because airway sloughing may quickly occlude smaller diameter endotracheal tubes. Frequent in-line suctioning to maintain a patent airway and fiberoptic bronchoscopy should be performed as soon as feasible to document extent of injury as well as to remove large plugs under direct vision. During fiberoptic bronchoscopy, large-volume saline lavage is contraindicated because this will only wash debris deeper into smaller airways. Preemptive intubation should be considered in all patients with large burns and those expected to receive a large volume of crystalloid resuscitation because eventual pharyngeal edema may make intubation difficult if not impossible. Furthermore, burn casualties who require transport, especially by rotor or fixed-wing aircraft, should have a definitive airway established before movement between sites.

In addition to burn wounds, primary and secondary survey of the casualty may reveal multiple injuries to include intra-abdominal injuries as well as significant soft tissue wounds and long bone fractures, an observation noted among a significant number of military burn patients (6, 7). Many military as well as 20% of civilian burn casualties sustain their burn injuries while traveling in moving vehicles and therefore need evaluation for blunt trauma as well as penetrating injuries (1, 5). As patient stability dictates, computed tomography scanning should be used to identify injuries in the multitrauma and plan operative intervention and sequence (Fig. 1). Those who are hemodynamically unstable despite initiation of appropriate resuscitation or who are found to have life-threatening injuries are moved directly to the operating room for exploration and treatment.

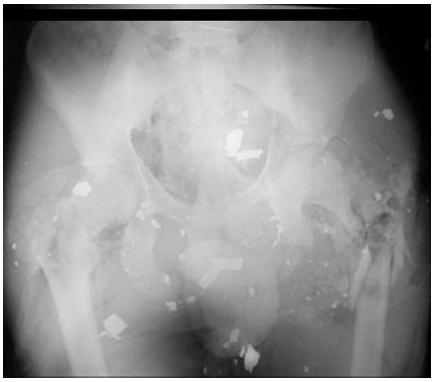


Figure 1. Computed tomography scan revealing fracture beneath burned tissue.

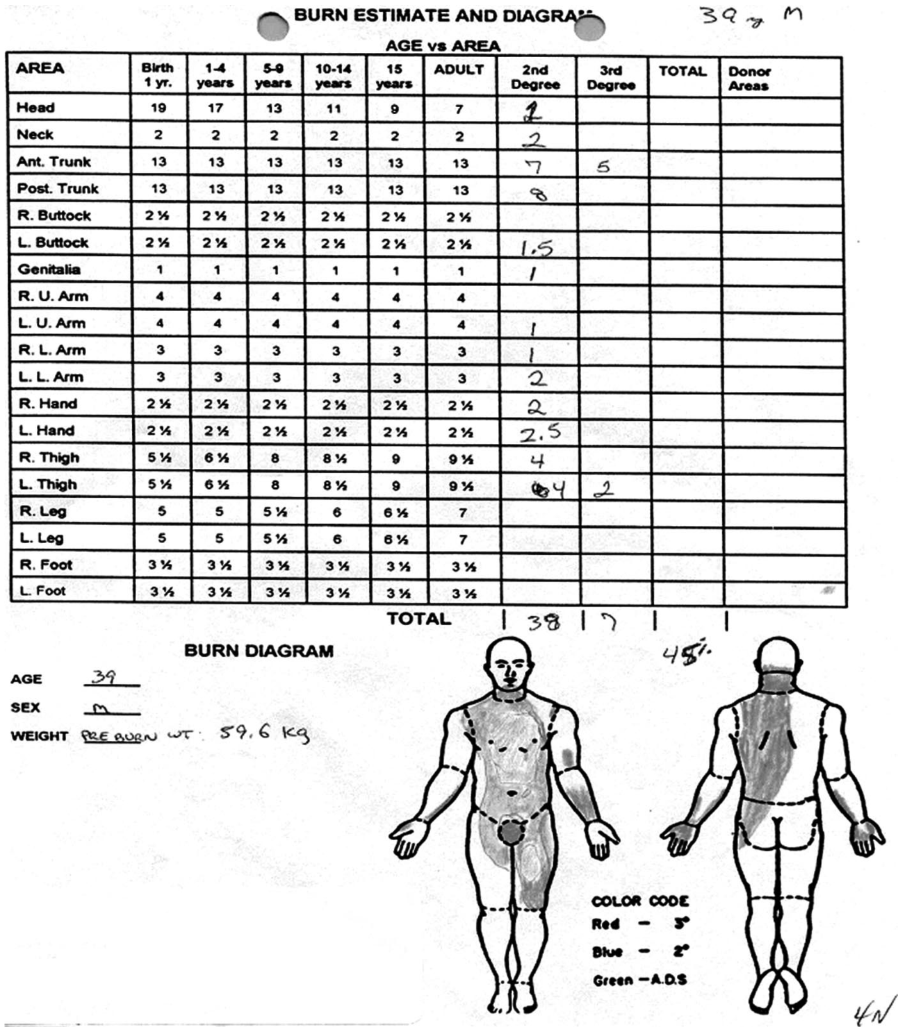
In a deployed environment, burn patients are transported to the operating room for treatment of associated injuries and debridement and dressing of all wounds because this location often provides the cleanest, most well-lit environment possible and anesthesia is readily available as needed. Here, the extent and depth of burn is accurately estimated with a Lund-Browder chart (Fig. 2) and a vascular examination is repeated and documented. Circumferential burn wounds involving the extremities are prone to the tourniquet effect of the inelastic burn eschar. This is further exacerbated by fluid resuscitation, which causes tissue edema, increased tissue pressure, vascular compression, and ischemia. In these cases, escharotomies are performed by dividing the burn eschar to the fatty tissue beneath and allowing the wound to decompress through the incisions. Escharotomies are created on the lateral and medial aspects of the limbs, avoiding any underlying neurovascular structures (for example, saphenous vein, ulnar nerve) and leaving the fascia intact (Fig. 3). Although it is an urgent procedure easily performed at the bedside, escharotomy is ideally performed in a clean environment using electrocautery to ensure hemostasis. A vascular examination is repeated after the procedure to verify effectiveness of the procedure. Early escharotomy should be considered for any patient with a deep, circumferential burn who will be transported, regardless of the results of physical or vascular examination.

With the exception of high-voltage electrical injury, fractured bone deep to the burn wound, or vascular injury to the limb, fasciotomies of burned extremities are rarely required (7). If compartment syndrome is suspected after a report of pain, tense or swollen extremity, or decrement or absence of pulses, escharotomies should be performed in the setting of a circumferential burn wound and compartment pressures measured. Fasciotomies are performed only when findings indicate compartmental hypertension and should not be performed prophylactically except in the circumstances described. If frankly necrotic muscle is identified at the time of compartment release, it should be entirely debrided to healthy tissue and steps taken to guard against and treat rhabdomyolysis.

Burn patients, as a result of their inability to maintain thermoregulation, are at higher risk of becoming hypothermic. In the multitrauma patient, this may worsen the coagulopathy and acidosis already present. In addition, escharotomy and/or fasciotomy sites may bleed under dressings if the patient becomes hypothermic during transportation. Prolonged exposure to cold should be minimized. This requires planning when transporting burn patients between facilities. Safeguards to prevent hypothermia should be aggressively implemented, including the use of space blankets and other passive warming measures such as heat lamps, Baer Hugger (Augustine Medical, Eden Prairie, MN), and/or warm intravenous fluid solutions. Cooling gel pads intended for comfort or pain relief in the burn patient with large surface area burns should be avoided.

Resuscitation

The most difficult and controversial aspect of care for the burn patient continues to be providing the optimal resuscitation during the first 24 to 48 hrs after injury. Severe burn injuries cause massive fluid shifts from the intravascular



BURN ESTIMATE AND DIAGRAM

39 y M

AGE vs AREA

AREA	Birth 1 yr.	1-4 years	5-9 years	10-14 years	15 years	ADULT	2nd Degree	3rd Degree	TOTAL	Donor Areas
Head	19	17	13	11	9	7	1			
Neck	2	2	2	2	2	2	2			
Ant. Trunk	13	13	13	13	13	13	7	5		
Post. Trunk	13	13	13	13	13	13	8			
R. Buttock	2½	2½	2½	2½	2½	2½				
L. Buttock	2½	2½	2½	2½	2½	2½	1.5			
Genitalia	1	1	1	1	1	1	1			
R. U. Arm	4	4	4	4	4	4				
L. U. Arm	4	4	4	4	4	4	1			
R. L. Arm	3	3	3	3	3	3	1			
L. L. Arm	3	3	3	3	3	3	2			
R. Hand	2½	2½	2½	2½	2½	2½	2			
L. Hand	2½	2½	2½	2½	2½	2½	2.5			
R. Thigh	5½	6½	8	8½	9	9½	4			
L. Thigh	5½	6½	8	8½	9	9½	4	2		
R. Leg	5	5	5½	6	6½	7				
L. Leg	5	5	5½	6	6½	7				
R. Foot	3½	3½	3½	3½	3½	3½				
L. Foot	3½	3½	3½	3½	3½	3½				
TOTAL							38	7		

Figure 2. Lund-Browder chart.

Figure 3. Escharotomy of lower extremity.

space to the interstitium in both burned and nonburned tissues. The resulting hypovolemia causes a reduction in cardiac output and an increase in systemic vascular resistance, all of which worsen the shock state. Prompt volume replacement with crystalloid solutions sufficient to maintain adequate perfusion of vital organs reverses burn shock and is lifesaving. However, resuscitation is less straightforward for military casualties who have other severe injuries (5). The risks and complexities of initial burn resuscitation and evacuation are increased in this critical period and often undertaken by physicians and nurses who do not specialize in burn care (10). To improve care for military burn patients, burn resuscitation guidelines (BRG) using a modified Brooke formula (lactated Ringer's solution initiated at 2 mL/kg/% TBSA divided over the first 24 hrs) (Fig. 4*A–B*) and a burn resuscitation flow sheet (BRF) (Fig. 5) were developed to assist providers in the deployed environment. Initially distributed in January 2006, these guidelines, along with system-wide standardization burn wound care and focused education for deploying medical personnel through Combat Burn Life Support classes, have improved outcomes in severely burned patients in Operation Enduring Freedom and Operation Iraqi Freedom (11).

As stated in the guidelines, the resuscitation regimen should administer no more fluid than is necessary for end-organ perfusion as measured by adequate urine output, generally accepted as 30 to 50 mL per hour in adults. Intravenous fluid rates are adjusted hourly, avoiding boluses of fluid and making incremental adjustments by 20% to 25%. Inadequate resuscitation can lead to ischemia of pulmonary, renal, and mesenteric vascular beds and can worsen end-organ insult and injury. Overresuscitation, termed resuscitation morbidity, produces its own constellation of complications that may include upper airway obstruction, pulmonary edema and cerebral edema, extremity compartment, and abdominal compartment syndrome (ACS).

To minimize resuscitation morbidity, the projected 24-hr resuscitation should be calculated at 12 hrs postinjury. If this estimate is found to be greater than 6 mL/kg/%TBSA (or approximately 16 L in a 70-kg man), then steps are taken as outlined in the BRG (Fig. 4) to minimize fluid infused. Bladder pressure is measured at intervals. In the face of ACS, abdominal escharotomies and peritoneal drain placement may be performed (12); however, decompressive laparotomy is almost always required. The mortality of ACS in severe burn patients exceeds 80% (13).

Higher morbidity and mortality of burned casualties evacuated from theater was directly linked to overresuscitation. Once implemented theater-wide, the BRG and BRF have resulted in a reduction of patients with ACS and death (11).

Patients with evidence of myonecrosis or rhabdomyolysis such as that seen with crush or electrical injuries or compartment syndromes are at risk for acute tubular necrosis and acute kidney injury, which has a reported mortality greater than 70% in severe burns (14). Once recognized, the source must be rapidly identified and controlled. Intravenous fluid rates should be increased for a target urine output of 1 mL/kg/hr, commonly between 75 and 100 mL/hr. This can usually be accomplished with volume loading, which causes a solute diuresis and removes toxins from kidney tubules.

In difficult cases, diuresis with mannitol or furosemide may be instituted but may result in hypovolemia and invalidates urine output as a reliable measure of resuscitation. To prevent precipitation of myoglobin in the renal tubules, alkalinization of the urine with sodium bicar-

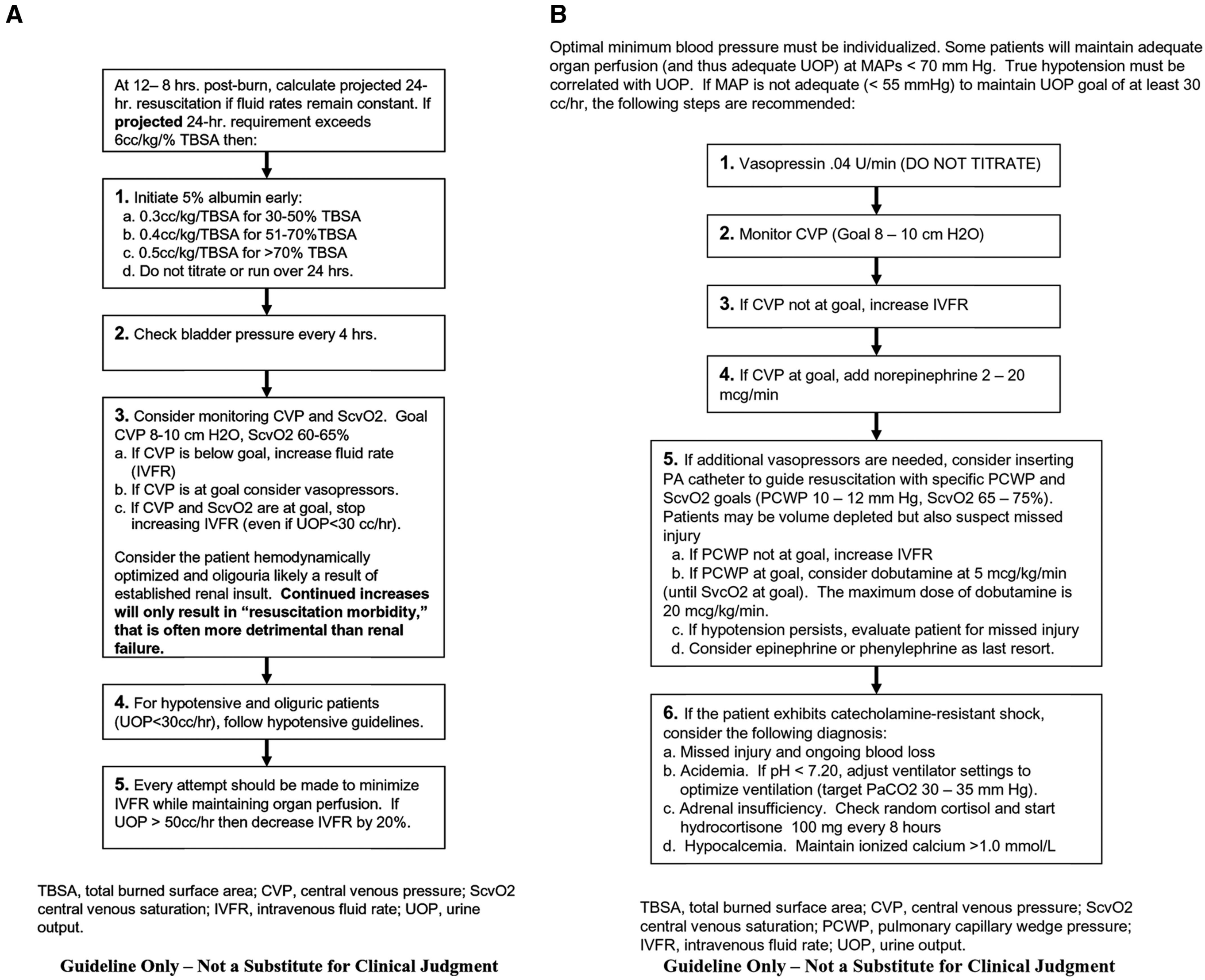


Figure 4. *A,* Joint Theater Trauma System clinical practice guidelines for burn care: recommendations for difficult fluid resuscitation in complicated burn care. *B,* Joint Theater Trauma System clinical practice guidelines for burn care: recommendations for hypotension in complicated burn care. *MAP*, mean arterial pressure; *PA,* pulmonary artery.

bonate has been advocated; however, this treatment may worsen hypocalcemia, especially when hypovolemia is corrected. Neither mannitol nor sodium bicarbonate has been shown more effective than volume loading in the treatment of rhabdomyolysis (15, 16).

Acute burn patients are also at risk for electrolyte derangements, especially hyperkalemia, thus serum electrolytes and creatinine kinase (CK) must be monitored frequently and treatment should continue until CK is less than 5000 U/L. In cases in which CK does not decline appropriately or actually rises during treatment, source control should be verified in the operating room. In refractory cases such as seen with oliguric or anuric renal failure with volume overload or persistent hyperkalemic acidosis, renal replacement therapy should be considered (17).

Hemodynamic monitoring of the burn patient during resuscitation is optimized as the patient progresses through the levels of care. Initial vital sign monitoring beginning with assessment of pulses and manual measurement of blood pressure rapidly advances to include continuous heart rate monitoring, pulse oximetry, and interval-automated blood pressure measurements as the patient is evacuated to the first medical treatment facility. Before surgery, placement of arterial and central venous catheters provides continuous measurements of arterial blood pressure and central venous pressure. Central venous pressure measurements and central venous saturations can also play a key role in the decision algorithms of the BRG.

Care of the Burn Wound

Patients with large burn wounds are routinely debrided at the first medical facility able to provide this service. The distance between such a facility and the place of injury may vary considerably (4). Initial debridement of the large burn wound is best performed in a clean, warm operating room with anesthesia support, resuscitation capability, adequate lighting, and appropriate dressing materials. Debridement of the burn may be relatively superficial, requiring cleansing with antimicrobial soap and water followed by placement of the topical dress-

JTTS Burn Resuscitation Flow Sheet Page 1

Date: Initial Treatment Facility:

Name	SSN	Pre-burn Est. Wt (kg)	%TBSA	Estimated fluid vol. pat. should receive 1st 8 hrs	2nd 16th hrs	Est. Total 24 hrs

Date & Time of Inury

BAMC/ISR Burn Team DSN 312-429-2876

Tx Site/ Team	HR from burn	Local Time	Crystalloid / Colloid	TOTAL	UOP	Base Deficit	BP	MAP (>55)	CVP	Pressors (Vasopressin 0.04 u/min)
	1st									
	2nd									
	3rd									
	4th									
	5th									
	6th									
	7th									
	8th									
	Total Fluids:									
	9th									
	10th									
	11th									
	12th									
	13th									
	14th									
	15th									
	16th									
	17th									
	18th									
	19th									
	20th									
	21st									
	22nd									
	23rd									
	24th									
	Total Fluids:									

Figure 5. Burn resuscitation flow sheet. *JTTS*, Joint Theater Trauma System; *TBSA*, total burn surface area; *UOP*, urine output; *MAP*, mean arterial pressure; *BP*, blood pressure; *CVP*, central venous pressure.

ing. This process may include debriding residual blisters, especially if the blisters are large (>2 cm) or cover large surface areas. However, it is recommended that blisters overlying partial-thickness burns be left intact until such time as definitive wound care, in a clean environment, can be performed. More extensive debridement of the burn may be required, especially when escharotomies or fasciotomies are performed or when multiple associated soft tissues injuries require removal of nonviable soft tissue and hemostasis must be achieved before placement of the dressing to avoid masking hemorrhage.

The choice of which topical burn dressing to apply to the wound is based on several factors: material at hand, provider preference, adjacent wounds, anticipated time, and distance between successive medical facilities (and therefore when dressings will be reinspected and changed). Providers in the field should simply cover burns with a clean, dry dressing and avoid applying any topical ointments, including burn creams. This approach circumvents the necessity to remove ointments or creams at the formal debridement and also discourages gel cooling blankets or dressings that may contribute to hypothermia. Prophylactic antibiotics are not needed and may promote the emergence of resistant organisms, and tetanus prophylaxis should be verified and updated if needed.

Once the burns have been formally cleansed and debrided, dressing the wounds in a silver–nylon dressing (for example, Silverlon, Argentum Medical, LLC, Willowbrook, IL; SilverSeal, Noble Biomaterials, Scranton, PA) covered by layer gauze provides a clean, protective milieu that uses the silver ion as the antimicrobial agent. This dressing is effective for many hours to several days without the need for reapplication of the topical agents such as Silvadene (BASF Corporation, Shreveport, LA) or Mafenide (UDL Laboratories, Inc., Rockford, IL) creams. The silver–nylon dressings are also easy to apply and maintain throughout the evacuation process.

Often burn wounds involve contiguous areas of open soft tissues wounds that resulted from direct tissue loss, degloving injuries, or surgical debridement. Wounds of this nature are left open for serial debridement and until definitive coverage or closure can be performed. In many cases, negative pressure wound dressings such as the vacuum-assisted closure (VAC) dressings that use open-pore foam (Kinetic Concepts, San Antonio, TX) are ideal. These dressing are easily conformable to the wound beds, facilitate removal of exudate, and expedite granulation.

Communication and Early Consultation

As outlined in the tenants of the Advanced Burn Life Support course, the ABA has long espoused the value of early communication between the provider initiating transfer of the burn patient and the provider at the receiving burn center (9). Early communication is valuable when the healthcare professional providing the initial care does not have extensive or recent experience caring for severe burns or the burn casualty requires a lengthy evacuation process. Both telephone and e-mail aid in the timely discussion of the burn patients and management along the continuum of care. The capability of the Internet to electronically transmit photographs or video of the burn casualty, often in real time, has become an invaluable resource, especially for primary care providers in remote areas.

To facilitate the management of military burn casualties worldwide, the USAISR Burn Center staff members are continuously available by phone or e-mail for consultation. Since early 2005, a burn surgeon has deployed to Iraq to serve as both a trauma surgeon and theater con-

sultant for burns. Although the burn surgery consultant is not able to examine every burn patient, he or she is able to provide rapid consultation and facilitate evacuation as needed. A weekly theater-wide video teleconference allows providers at all echelons of care the opportunity to review and discuss challenging cases involving burns and other traumatic injuries. This forum provides and effective platform for real-time discussion and problem-solving as well as means of patient follow-up and quality improvement.

Long-range Evacuation and Transport

The ability to safely transport burn casualties across long distances, while continuing resuscitation, allows expeditious delivery of the patient to the facility able to provide definitive care (2, 18). This capability is a key to the overall process of burn care for military burn casualties because it minimizes ventilator days and facilitates prompt excision and grafting and early rehabilitation therapy. Policy regarding the transport of burn casualties is fashioned around guidelines similar to those published by the ABA for burn center admission criteria, which in turn are based on the severity of burn injury, the presence and severity of inhalation injury, and other associated injuries.

Patients with severe burns, typically those with large burns (>50% TBSA) and/or inhalation injury, are transported to USAISR Burn Center by the Army's Burn Flight Teams. The Burn Flight Team has provided worldwide transport of patients with severe burn injuries since the early 1950s. Each team is comprised of a general surgeon, a registered nurse, a licensed vocational nurse, a respiratory therapist, and an operations officer, each of whom work daily in the intensive care units of the burn center.

For patients requiring mechanical ventilation during flight, the choice of ventilator and ventilator mode during transport is based on the patient's severity of injury, pulmonary status, and response to mechanical ventilation. Patients with inhalation injury can require significant ventilatory support beyond the capabilities of conventional devices. Experience with the volumetric diffusive respirator (VDR) by USAISR burn center to treat patients with inhalation injury and other severe pulmonary dysfunction has led to extensive use of the VDR in

Figure 6. TXP transport ventilator.

patient transport. The TXP pressure control ventilator (Percussionaire Corp., Sandpoint, ID) is also used in the evacuation of patients because of its simplicity, compact size, and effectiveness (Fig. 6). Both the VDR and TXP are driven by compressed air or oxygen, have no electrical requirements, and are cleared for use on all military aircraft.

Burn evacuees are carefully assessed before departure to ensure they are capable of tolerating the transcontinental flight, often 12 to 13 hrs in duration. Concerns regarding long-range flight and prolonged bedrest and immobility heightened concern for deep vein thrombosis among evacuated patients. In an effort to reduce the risk of deep vein thrombosis and pulmonary embolism, chemical prophylaxis with low-molecular-weight heparin is often administered before and in flight unless specifically contraindicated. Enteral feeding delivered through a nasoenteric feeding tube is often initiated within 48 hrs after injury and is continued during flight using a paired nasogastric tube to ensure gastric decompression.

Burn Center Care

After being transported thousands of miles, the military casualty often arrives at the burn center within 3 to 4 days postinjury. During this time, the patient has undergone one or more operations for debridement and dressing of burn wounds and treatment of associated injuries when present. The initial excision of deep partial to full-thickness burn wounds is done as soon as possible after arrival, recognizing that this may be postburn day 4 or 5 for patients who were injured on the opposite side of the globe. Because the burn casualty has often sustained other injuries, early cooperation and coordination of care with consulting services (for example, orthopedics, ophthalmology, neurosurgery) minimizes delays in diagnosis and treatment. This interdisciplinary approach to care maximizes operating time and resources and allows the consulting services to perform detailed examinations and procedures in conjunction with the initial excision and grafting operation.

Clinical Research

One of the most effective pathways to improve clinical care is through research. This begins at the point of injury and proceeds through care of the burn wounds and beyond to include rehabilitation, reconstructive surgery, and analysis of outcomes. The Burn Center for the Department of Defense is part of USAISR and is ideally positioned to perform clinical studies designed to improve care through careful analysis of injury patterns and treatment outcomes.

Since the beginning of current U.S. military operations in Iraq and Afghanistan, USAISR has worked to collect and analyze patterns of injury and assist in the development of improved items of clothing and equipment to help protect our warriors. Injury prevention and protection measures are key components to improved survival on the battlefield, and many of the practices and products developed during wartime are later translated to civilian life.

CONCLUSIONS

Rapid and effective treatment of the severely burned patients requires a system of early communication and consultation as well as essential education for those providers who initiate care of the burn and trauma patient. The BRG and use of the BRF has encouraged theater-wide standardization of care for the burn casualty and resulted in improved outcome for wounded warriors. These improvements can be directly translated to civilian care systems and USAISR is working to implement this type of information exchange within the south Texas regional trauma system.

The military has made enormous progress with respect to the treatment of burn casualties, yet many challenges remain. Data regarding host nation casualties is now being analyzed, which provide for a better transition of care between military and civilian facilities within the host nation. Long-range transport of severely injured casualties continues to push the limits of our evacuation system and research focused on the development of improved monitoring devices, telemedicine, and computer-based technology to assist with resuscitation is ongoing.

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